Art. XVI.—*Physical Constants of Thallium.*

(With Plate XVII.)

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Being in possession of a piece of thallium, and being unable to find its constants in the ordinary books of reference, I determined a few of them as follows. The investigation was conducted in the Physical Laboratory of the University of Melbourne.

(1) Coefficient of Expansion.

A piece of the thallium was drawn into a wire about fourteen inches long, the ends cut off square, and a nick made near each end. It was put into a glass tube through which steam could be passed at will from a small boiler. The ends of the tube being firmly clamped, micrometer microscopes were focussed on the ends of the wire. These instruments, supplied by the Cambridge Scientific Instrument Co., read to $\frac{1}{10000}$ inch. The positions of the ends of the wire and of the outer and inner edges of each nick were observed, the observations being repeated several times. The temperature of the thallium was assumed to be that indicated by a thermometer left lying beside the glass tube all night, 16·8° C. Steam was then passed along the tube till it was fairly dry, and after about fifteen minutes, the observations of the positions of the nicks and ends of the wire were repeated, the temperature being assumed to be 100° C. The gain in length of the whole wire was observed to be ·0261 inch, between the outer edges of the nicks ·0255 inch, and between inner edges ·0255 inch. On replacing the glass tube by a scale, the length of the wire was found to be 13·83 inch, and the distance between the nicks 13·69 inch. Dividing the increase in length by the rise in temperature (83·2°), and by the length measured, the coefficients come out ·0000227, ·0000224, ·0000224, giving as mean result ·0000225.

(2) Specific Resistance.

I at first made several determinations of the resistance of the thallium, in the form of short thick wires, and compared its resistance with silver, and afterwards with lead, and separately determined the resistances of the specimens used in comparison. I found it much more accurate however to draw the thallium into a finer wire, and determine its resistance directly. This was done with a resistance box, with a shunt on the variable arm. It was measured several times at slightly different temperatures, as shown in the following table :—

t	r	s	R^1	R
21	·16	5·80	·1557	·1551
21·8	·16	6·55	·1562	·1551
22·1	·16	6·87	·1564	·1551
22·1	·17	1·95	·1564	·1551

t is the temperature centigrade, r and s are the two resistances in parallel which balance the resistance of the thallium. R^1 is $\frac{rs}{r+s}$, the observed resistance of the thallium, and R is the resistance at 20° C., reduced by the coefficient ·0039 (*vid. inf.*) The length of the thallium was 46·14 cm., and the mean value of diameter measured at different parts along it was ·0874 cm., the mean error in measuring it being ·0005 cm. The specific resistance at 20° C. is therefore $\frac{\pi \times \cdot 0437^2 \times \cdot 1551 \times 10^9}{46 \cdot 14} = 20170.$

(3) Variation of Resistance with Temperature.

To determine this, the thallium was made into a small coil, and immersed in a large beaker of water, with a thermometer about the middle of the coil. The thallium was connected with the terminals of a slide metre bridge by means of two stout pieces of copper, to which it was firmly bound, and whose resistance was found to be about $\frac{1}{100}$ of that of the thallium. The resistance of the thallium was balanced with an approximately equal resistance of German silver, which was taken as an arbitrary unit to measure the resistance of the thallium at different temperatures. By means of a very sensitive galvanometer, the slider could be adjusted to ·1 mm., while the whole change in position for a rise of 80° C. was about 70 mm. In reducing the bridge readings to resistances, correction was made for the fact that the middle point of the wire was not the electrical centre, which was 3·3 mm. to one side, and the resistances were diminished by 1 per cent. of the cold resistance of the thallium on account of the copper connections. Two independent sets of observations were made, and from each the coefficient at 20° C. was calculated by the method of least squares. The figures from which the calculations were made are given in the annexed table :—

Set 1.		Set 2.	
t	*R*	*t*	*R*
17·8	·987	16·2	1·017
30·5	1·035	32·1	1·079
41·4	1·074	48·2	1·143
51·7	1·102	61·4	1·196
62·1	1·154	79·8	1·274
80·3	1·227	99	1·357
98·8	1·312	85·1	1·298
		72·2	1·246
		67·5	1·226

The values of the coefficient from the above tables are ·00394 and ·00400.

Having determined these values by means of the slide bridge, I proceeded to verify the result by measuring the resistances with a resistance box, and shunt as described above. Two independent sets of observations were made as before. The observed values are given in the following table :—

Set 3.		Set 4.	
t	*R*	*t*	*R*
18·1	·2054	17·3	·2134
32	·2162	59·3	·2490
40·6	·2228	80·9	·2679
53	·2329	99·3	·2842
60·7	·2381	54	·2456
72·1	·2488	24·9	·2232

The values of the coefficients from sets 3 and 4 are ·00384 and ·00391. The mean of these four gives, as the coefficient at 20° C., ·00392. This is larger than the value for most metals other than iron.

(4) Thermo Electric Height.

As I had a piece of pure silver, and no other metal pure, I resolved to find the thermo electric height of thallium with regard to silver, and assume Professor Tait's result for silver in order to obtain the absolute value for thallium. Having done so, it was found that the thallium line thus determined, crossed Professor Tait's copper line at about 70° C., and that copper was therefore an exceptionally favourable metal with which to compare thallium. I therefore obtained pure copper and compared thallium with it, and found that thallium was further below copper than below silver; and on finally trying copper and silver, I found the lines should be very much closer together than they are in Professor Tait's diagram, and that copper should be above silver and not below it. I therefore purified some lead, and constructed a diagram of my own for the four metals—lead, thallium, copper and silver. To obtain pure lead, I dissolved some sheet lead in nitric acid, and precipitated it as sulphate by adding dilute sulphuric acid. The sulphate thus obtained was heated with carbonate of soda and cream of tartar in a Hessian crucible in an injector furnace, and lead obtained which was assumed pure, though it contained a trace of potassium. I used an astatic low resistance galvanometer with a lamp and scale, at a distance of about four feet, the scale divisions being fortieths of an inch. The resistance of the galvanometer was somewhat less than an ohm, but with the leads and the wires of the thermo electric circuit, the resistance was a little over an ohm. So low an E.M.F. as ·000001 volt or 100 absolute units gave a deflection of one scale division. This appears to be about 30 times as sensitive as the one used by Professor Tait twenty years ago. To determine the exact value of a scale division, the galvanometer was joined in series with an ordinary Daniell cell and various high resistances, and immediately after or before its E.M.F. compared with a Latimer Clark cell, by means of a condenser and balliatic galvanometer. In examining the thermo electric power of two metals, I twisted together their ends and coiled the joint round the bulb of a thermometer, immersing the whole in a bath of olive oil. The other junction was kept in a large beaker of cold water with a thermometer in it, which was observed from time to time, and if necessary, correction made for the rise of temperature. This rise was never more than a degree, the corresponding correction being one or two scale divisions. The relation between the observed values of temperature and galvanometer reading is parabolic, and if we express the excess of the temperature of the hot junction over the cold by t, and the number of scale divisions by s, then $s = a\,t + b\,t^2$ is the connection between s and t, where a and b are constants to be determined preferably by the method of least squares, as was done with each set of observations, though the operation is rather laborious. The following table may be taken as typical of the accuracy attained :—

T	s (*observed*)	s (*calculated*)
19	0	0
76	114	119
73	107	112
70	102	108
76	115	119
131·7	206	201
130	202	199
180·3	249	249
200	259	260
184	249	250
179	246	247
161	232	232

In this case, the metals being thallium and lead, the resistance of the circuit was 1·395 ohm. The equation to the parabola, represented by the first and second columns, is $s = 2{\cdot}36\,t - {\cdot}00512\,t^2$ where $t = T - 19$. A Daniell cell, when used to charge a condenser, gave a throw of 276·3 sc. divs.; a Latimer Clark cell gave 346·4; the E.M.F. of the Daniell is thus—$1{\cdot}435 \times 276{\cdot}3 \div 346{\cdot}4 = 1{\cdot}144$.

The same Daniell, when connected in series with the galvanometer, gave a deflection g for resistance R. If the

g	R
142·5	12000
176	10000
195	9000
246	7000
287	6000
213	8000

current through the galvanometer be $k\,g$, then $\frac{1·144}{R} = k\,g$, or $k = \frac{1·144}{R\,g}$. Now the mean value of $R\,g$ is 1729000, therefore $k = \frac{1·144}{1729000}$. If e be the electromotive force of the thermal circuit, and r its resistance, then $e = k\,s\,r$, or the electromotive force corresponding to one scale division is $\frac{1·144 \times 1·395}{1729000}$ volt, or 92·3 absolute units of electromotive force.

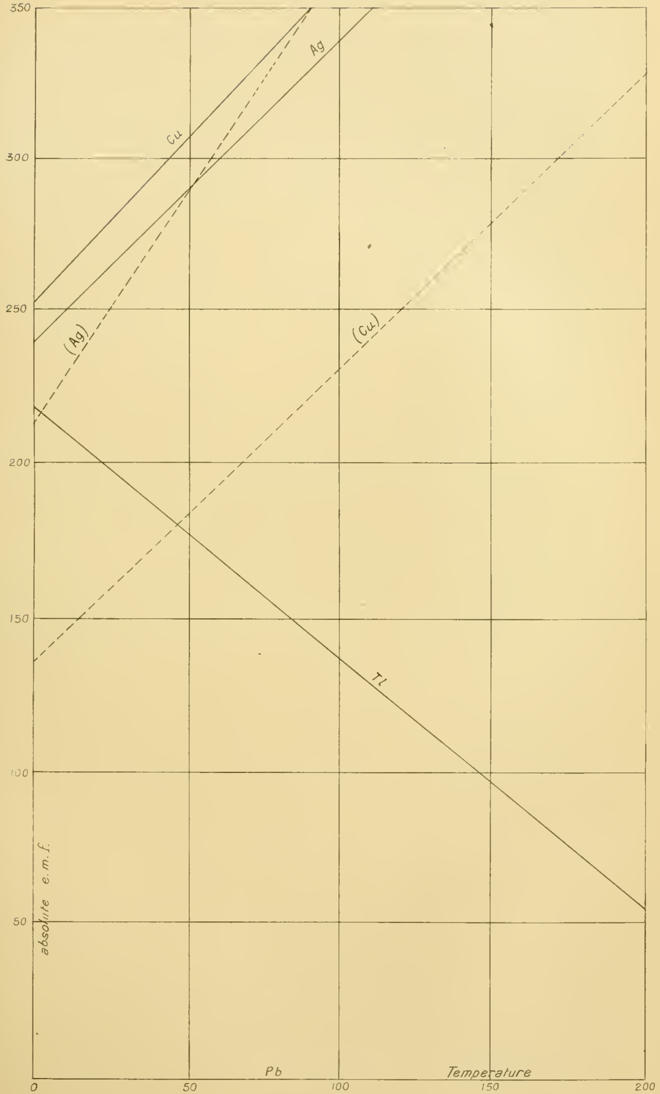
Now $s = 2·36t - ·00512t^2$, or if we measure the temperature from the neutral point of the two metals, $s = ·00512t^2$. If the temperatures be the neutral point, and 100° above or below it, and if m be the relative Thomson effect, then $51·2 \times 92·3 = 5000\,m$, and $m = ·94$.

To find the neutral point—$\frac{d\,s}{d\,t} = 0$, *i.e.*, $2·36 - 2 \times ·00512\,t = 0$, $t = 230$, *i.e.*, 249° C.; the height at 0° C. is therefore $249 \times ·94 = 234$. The thermo electric height of thallium above lead is thus—$234 - ·94\,t$, t here being temperature centigrade.

Another similar but independent set of observations gave as the height $198 - ·65\,t$, the mean of these being $217 - ·79\,t$. Of the four metals, each pair was taken together, and the following results obtained. In each case the higher metal is the first :—

1.	Thallium–Lead	$217 - ·79\,t$
2.	Copper–Thallium	$43 + 1·79\,t$
3.	Copper–Lead	$252 + 1·06\,t$
4.	Copper–Silver	$12 + ·10\,t$
5.	Silver–Thallium	$40 + 1·47\,t$
6.	Silver–Lead	$206 + 1·35\,t$

If we add the Thallium–Lead to the Copper–Thallium, we get $260 + 1·00\,t$, which agrees fairly well with the directly



350
300
250
200
150
100
50
0
50
100
150
200
Cu
Ag
(Ag)
(Cu)
Tl
absolute e.m.f.
Pb
Temperature